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PERFORMANCE OF BIOFILTRATION PLANTS BY THREE METHODS

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SANITARY ENGINEERING DIVISION

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AN EVALUATION OF THE PERFORMANCE OF CERTAIN BIOFILTRATION PLANTS BY THREE METHODS

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SYNOPSIS

High-rate filters have now become an accepted tool for biologic treatment of sewage, but design data for the average municipal plant have been developed largely on an empirical basis. An analysis of operating data from selected biofiltration plants shows that measures of performance can be defined which are applicable to economic designs of new plants and which permit the prediction of results with a greater degree of assurance.

Three methods of evaluating performance have been applied to several single-stage plants and the computed results compared to the actual. Of the three methods applied, the Velz formula for computed performance checked most accurately with the actual but, because of the ease of application, the Tentative Standards method of computing performance should prove as satisfactory. Two methods of evaluation have also been applied to several two-stage plants and again the Tentative Standards method of computing performance appears to be more applicable.

Where to use single-stage high-rate filters and where to use two-stage filters is discussed with an evaluation as to when it is more economical to use two-stage treatment.

A flowsheet is also described which is intended to produce an effluent of any degree desired between that from primary sedimentation and single-stage complete treatment.

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The high-rate filter installations which have been selected for study belong to the group classed as biofiltration plants as the author is most familiar with them. The term "biofiltration" as used herein refers to those high-rate filter plants which, in a single or two-stage plant, return some portion of the discharge of the filter to the influent of the primary sedimentation tank where it is united with the raw sewage. In this group there are a variety of arrangements or flowsheets but discussions will be limited to two typical flowsheets for single-stage, two for two-stage plants and a flowsheet for intermediate treatment. Intermediate treatment is intended for applications where conditions require more than primary sedimentation but less than complete treatment. The various flowsheets are shown in Fig. 1.

In biofiltration plants there are considerations which are not present in standard-rate trickling filter plants. Foremost among these is the permissable load which can be applied to the filter. Other factors include the dosing rate on the filter, the amount of recirculation to be used and where it can be most effectively applied, and whether to use a single or two-stage arrangement of filters. While some of these factors do concern the designer of standard-rate filters, long usage has developed well established factors for design purposes. Where to use a high-rate filter is a matter which must be decided by local conditions with particular reference to the receiving body of water.

BOD reductions in most biofiltration plants and in fact in most high-rate filter plants of any type, when dosed in excess of 10 mil. gal. per acre per day, will often equal or even exceed reductions in standard-rate filters although they will show little if any evidence of nitrification commonly associated with standard-rate filters. However, available analyses of biofiltration plant effluents do show substantial reductions in total organic nitrogen. It becomes a matter for the pollution control authority to decide whether a nitrified effluent is required of the biologic treatment step or simply adequate reduction in BOD. Judging by the proportion of high-rate to standard-rate filter plants constructed since World War II, a well nitrified effluent does not appear so essential as it was formerly. This factor, however, should not be overlooked when a high-rate filter plant is selected as the method of treatment.

In the discussion relating to performance of biofiltration plants, the measure considered as an index is the removal of BOD. Generally in biologic treatment plants the removal of suspended solids approximates that of BOD removal and if the latter meets requirements, the former is most likely to do the same providing reasonable operating care is exercised. This condition appears to hold for biofiltration plants as well, and hence the data on removal of suspended solids from the various plants will not be included although it is available.

BOD Removal by Sedimentation

Another problem arises in evaluating the BOD removal in the primary tank due to the sedimentation of the raw sewage. In plants with no recirculated flow returned to the primary, this is no problem as it involves simply an analyses of the influent and effluent. Where flow is recirculated back to the primary tank influent, this procedure will not give correct results and yet some means is needed to determine that portion of the BOD in the raw sewage which passes on to the biologic process. The method employed herein is to assume a certain percentage removal due solely to sedimentation based on the overflow rate in the primary sedimentation tank. The assumed removals and corresponding overflow rates are shown in Fig. 2 and these are essentially those contained in Tentative Standards for Sewage Works.[1] The residual BOD remaining in the sewage after subtracting the portion removed by sedimentation is considered as being the filter load.

Methods of Evaluating Performance

Three different methods have been used in evaluating the performance of the various biofiltration plants and it is necessary to explain each:-

1. Tentative Standards 1951 state "Type A (single-stage) filters will be considered where....the applied load recirculation included, does not exceed 110 lbs. 5-day BOD per 1000 cu. ft. (4800 lbs. per acre ft.) of filter media per 24-hr." Also, "the recirculation system shall apply sufficient dilution to the settled sewage so that the BOD of the influent to the filter, recirculation included, shall not exceed three (3) times the BOD of the required settled effluent."

The first statement indicates the maximum permissible loading under which the second statement applies. If the influent load to the filter including the recirculation must not exceed three times the effluent, then it may be concluded that the settled effluent will be one-third of the filter influent in a single-stage plant. Expressing values in parts per million and assuming that

the recirculated flow contains the same parts per million as the settled filter effluent, the following equation results for a single-stage plant:

$$e = \frac{c}{2R + 3}$$

in which:

e = BOD of settled effluent in ppm
c = BOD of settled raw sewage in ppm
R = ratio of recirculated flow to raw sewage flow

In Fig. 1(a) and 1(b) the recirculated flow is filter discharge settled either in the primary clarifier or in the final clarifier and hence the value of R is the ratio for the total volume recirculated through the filter and a settling tank.

According to the foregoing analysis, the efficiency, E, of the single-stage filter installation equals $\frac{R + 1}{R + 1.5}$ and is applied to the BOD of the settled raw sewage.

For two-stage filters the 1951 Tentative Standards state "the BOD load applied to the second stage filter, recirculation included, shall not exceed two times the BOD expected in the settled effluent. When the effluent of the first stage filter is applied directly to the second stage filter without intermediate settling, the assumed BOD removal by the first stage filter shall not exceed 50%."

Referring to Fig. 1(c) two-stage filters in series and again expressing the values in parts per million and assuming the recirculated flow from the second stage contains the same parts per million as the settled effluent the following equations result:

$$e_1 = 0.5c$$

and:

$$e_2 = \frac{e_1}{R_2 + 2}$$

in which:

c = BOD of settled raw sewage in ppm
e_1 = BOD of effluent of first stage filter in ppm
e_2 = BOD of settled effluent from second stage in ppm
R_2 = ratio of recirculated flow to raw sewage flow in the second stage

It will be noted that this method does not take into account any variation in the recirculation ratio in the first stage. From operating data on plants using this flowsheet it is evident that at least a recirculation ratio, R_1, equal to 1.0 should be used.

According to this analysis, the efficiency, E, of a two-stage filter system as in Fig. 1(c) equals $\frac{R_2 + 1.5}{R_2 + 2}$, which is applied to the BOD of the settled raw sewage.

It should be pointed out that the only reference in these Standards to rate of application to the filter is that the dosing rate shall be from 10 to 30 M.G.A.D. The only reference to filter volume is in the maximum allowable loading of high-rate filters.

2. The National Research Council formula [2] which was developed from operating data from plants serving military installations during World War II is as follows:

$$E = \frac{100}{1 + .0085\sqrt{\frac{W}{VF}}}$$

in which:

E = percent efficiency of BOD removal of the single-stage filter and accompanying clarifier
W = applied BOD loading in lbs. per day of settled raw sewage
V = volume of filter media in acre ft.
F = recirculation factor = $\frac{R + 1}{(0.1R + 1)^2}$
R = recirculation ratio

For two-stage filters, including an intermediate clarifier, the following formula is presented:

$$E_2 = \frac{100}{1 + .0085\sqrt{\frac{W_1}{V_2\ F(1 - E_1)^2}}}$$

in which:

E_2 = percent efficiency of BOD removal of the second stage filter and accompanying final clarifier
W_1 = BOD in lbs. per day in the effluent of the intermediate clarifier
V_2 = volume of filter media in acre ft. in the second stage
F_2 = recirculation factor for the second stage = $\frac{R_2 + 1}{(0.1R_2+1)^2}$
R_2 = recirculation ratio in the second stage
E_1 = effeciency of the first stage

This formula for the second stage is intended to take into account the decreased "treatibility" of the sewage entering the second stage.

Overall efficiency of a two-stage plant can be stated as follows:

$$E = E_1 + E_2 - E_1E_2$$

In applying this formula to the performance of two-stage plants with filters in series no allowance has been made for the omission of the intermediate clarifier. The omission of the intermediate clarifier should result in a lower actual efficiency than that computed by the formula.

3. Velz [3] has put forth a logical theory which he believes is applicable to all biologic beds. According to this theory the combined performance of a filter and accompanying settling tank is expressed by the following:

$$\frac{L_D}{L} = 10^{-kD}$$

where:

L = total removable fraction of BOD
D = depth of filter in feet
L_D = corresponding quantity of removable BOD remaining at depth D
k = logarithmic rate of extraction

For high-rate filters continuously dosed at a hydraulic rate of approximately 20 mil. gal. per acre per day Velz has estimated the value of k as 0.1505 and L as 0.784. These values have been used in computing the performance of the single-stage filters and likewise their efficiency. Variations from the dosing rate of 20 mil. gal. per acre per day have not been taken into account nor have the variations in sewage temperatures, both of which, Velz states, require consideration. Also, this method has not been applied to the performance of two-stage plants.

Singie-Stage Plants

Data from eight representative municipal plants operating according to flowsheets Figures 1(a) or (b) or minor variations thereof are analysed in Tables 1 to 4 inclusive. Six of the plants were in normal routine operation during the period represented by the data and two, Centralia, Missouri and Alisal, California were under special tests when the data were collected. All had been in seasoned operation prior to the time covered by the data.

Numerous other data from single-stage municipal plants were received but deemed unwise to include because of omission of essential facts necessary for accurate evaluation. It was also decided to omit any references to those plants serving the military or public institutions.

The data from Fremont, Ohio represent a one-month average of daily determinations, from Great Neck, New York an average of 24-month operation, from Oklahoma City, the average of six-month operating records, from Richland, Washington an average of 7-month operation, and from Dothan, Alabama 3 days tests by the Alabama Bureau of Sanitation under normal operating conditions. Centralia, Missouri data is taken from published[4] special tests by the U.S. Public Health Service; Storm Lake, Iowa data is from special tests under normal operating conditions; and Alisal, California data is from published[5] special tests. All data were weighted on the basis of flow in arriving at averages given in the table.

An examination of the plant locations (Table 1) shows a variety of climatic conditions possible although it should not be construed that the data relates to sub-zero temperatures when most biologic processes are at a minimum or cease altogether. In most cases the data represent temperate climatic conditions, which are the critical conditions most plants are required to meet.

The flow data and filter data show a wide variation in recirculation ratios, clarifier overflow rates, depths of filters and filter dosing rates. This can be expected when plants are designed according to various theories to meet certain assumed future conditions in a variety of areas. Table 2 shows the BOD at the various plants and here again, the loadings per unit of filter volume vary widely although none is approaching the upper limit or "breakthrough" level where reductions per unit of filter volume tend to decrease. Efficiencies of BOD removal are included not only on the settled sewage applied to the filter but also on the raw sewage as this is the real measure of performance for the plant as a whole.

Most interesting is the fact that the BOD in the effluents from these single-stage plants are under 30 ppm except for two plants with very strong sewage where the first stage biofiltration portion is followed by a second-stage of standard-rate filters. For the average municipal sewage it appears entirely feasible to produce an effluent of 20 to 25 ppm from a biofiltration plant.

Efficiency of Single-Stage Plants

Using the three methods described, the efficiencies in removing BOD have been computed and compared with the actual operating efficiency. Table 3 shows the results together with a ratio of actual to computed for removals from settled sewage. From these ratios it is apparent that the Velz method most closely agrees with the actual, the Tentative Standards method is a close second and the N.R.C. formula shows the greatest variation. Table 4 shows the same comparison for BOD removals from the raw sewage or overall plant performance.

Considering its simplicity and ease of application the method derived from the Tentative Standards seems most useful. The Velz method, although most accurate in comparison, is somewhat difficult to apply. Also in the strict application of the Velz theory, recirculation ratios could be considerably reduced and the plant would still yield the same effluent which would seem to require more substantiating evidence than is available. The N.R.C. formula while yielding readily to graphic solution is nevertheless somewhat unwieldy in application. A designer needs some method of determining plant proportions before it is built rather than a method of checking its actual performance later. The Tentative Standards method seems to serve this purpose in the simplest manner.

Two-Stage Plants - Filters in Series

Data from five representative plants are included which employ two stages of filters in series without intermediate settling tanks according to flowsheet in Fig. 1(c). All were in normal routine operation during the period represented by the data. Data from Winchester, Virginia covers an entire year and from Bentonville and Siloam Springs, Arkansas the data were collected over a period of four and five days by Arkansas State Board of Health during routine plant operation. Liberty, New York data cover a summer month when conditions were fairly uniform although operating data are available at this plant for over 12 years. The Medford, Oregon data cover a six-month operation which included the canning season. This plant, which was constructed in 1942, served Camp White during the war and has been taken over by the city. It now appears to be somewhat overloaded hydraulically. Data from several other plants were reviewed but unfortunately found wanting in information essential for this discussion.

An examination of the basic data of two-stage installations in Table 5 shows as in the single-stage plants a variety of conditions of recirculation, clarifier overflow rates and filter dosing rates. Table 6 shows the performance of these plants as measured by removal of BOD both from settled sewage applied to the filter and from the raw sewage. It may be noted that overall efficiency for all plants exceed 90%.

A comparison in computed vs. actual efficiency of BOD removal from settled raw sewage is given in Table 7 and from the raw sewage or overall efficiency in Table 8. The efficiencies in both tables were computed using the Tentative Standards method and the N.R.C. formula. In applying the latter no allowance has been made for the omission of the intermediate clarifier normally assumed to be in the flowsheet. However, it should be observed that in three of the plants, actual performance is higher than computed according to the N.R.C. formula. As in the single-stage plants the Tentative Standards method of computing performance deviates from the actual less than the N.R.C. method.

Again considering its simplicity, the Tentative Standards method seems to offer the most practical means for predicting performance of two-stage plants with filters in series. One reservation should be made in applying the Tentative Standards and this refers to the amount of recirculation in the first stage. Theoretically, recirculation could be reduced to zero and the same mathematical efficiency would result. Practically, however, data are insufficient to prove this point and operation of actual plants indicate an absolute minimum recirculation ratio of 0.5 but preferably 1.0 or more.

Intermediate Treatment

Occasion often arises when the stipulated reduction in BOD is to be somewhat greater than can be accomplished by sedimentation alone but somewhat less than from a complete single-stage plant. Raw sewage flocculation is occasionally applicable but frequently this will be inadequate. One solution lies in the use of the flowsheet Fig. 1(d) which consists of a clarifier and filter in series, the filter effluent returning to the clarifier influent and the plant effluent withdrawn from the clarifier effluent. This flowsheet is in use in a considerable number of plants, principally in the west, but unfortunately it was not possible to obtain any useful operating data in time.

An analysis of this flowsheet will show that settled effluent from the clarifier must be passed once through the filter before recirculation can be established. Hence the flow to the filter equals $Q + RQ$ where Q is the average raw sewage flow and R is the recirculation ratio. The clarifier must be capable of handling the filter effluent in addition to the raw sewage flow which results in a total flow into the clarifier equal to $Q(R + 2)$. This increased capacity of the primary clarifier serves in place of a separate final clarifier for settling the filter effluent. The difference is that this settled filter effluent constantly unites with the settled raw sewage thus resulting in a substantial reduction in BOD of the settled raw sewage.

The expected performance of a plant using this flowsheet (Fig. 1(d) is shown in Fig. 3. This performance has been computed, using the Tentative Standards, by assuming repeated passage through the filter of weighted volumes of settled raw sewage and settled filter effluent. The plant effluent is that portion of this mixture equal to the raw sewage flow.

Two-Stage Series-Parallel Filters

A further application of the intermediate plant flowsheet consists in expanding it by the addition of a second stage which results in flowsheet Fig. 1(e). This flowsheet has some unusual characteristics. A portion of settled raw sewage is constantly passing to the second stage filter thus assuring a more even distribution of the initial food supply between the two stages. This should permit the second stage to function with the same efficiency as the first stage because the "treatibility" of the sewage should be the same for both filters. In a gravity-flow plant using this flowsheet the two stages of filters can be placed at approximately the same elevation, with pumping requirements equal to $Q(R_1 + 1)$ in the first stage and QR_2 in the second stage, Q being the average raw sewage flow and R_1 and R_2 being the recirculation ratios in the first and second stage respectively.

The evaluation of performance of plants using this flowsheet (Fig. 1e) can be obtained by reference to Fig. 4. This diagram has been computed by applying the performance of a single-stage filter using the Tentative Standards method to the effluent from an intermediate type plant. In the practical

application of this flowsheet it should be observed that when the same overflow rates are selected for the primary and final clarifiers, they will be of identical size when R_2 equals $R_1 + 1$. The filter volume is usually determined by computing the total required and dividing it equally between the primary and secondary filters.

Operating data from plants using this flowsheet (Fig. 1e) are very meager although some 25 to 30 plants, mostly in the far west, have utilized it. It is possible that the limited use of this flowsheet has been due to unfamiliarity with it. Two widely separated plants have yielded sufficient data to give some idea of performance and this is shown in Table 9. The Orlando, Florida data covers an entire year of operation although since this plant is relatively new the actual flow is only about half of design flow. The data from the Petaluma, California plant was obtained during a 5-day test period in 1939 conducted by personnel from the author's employer. The unusual strength of sewage in this plant was due to wastes from poultry packing plants and other similar industries. Incidentally, the Petaluma plant built in 1938 is being enlarged in 1953, 15 years later due to a greatly increased tributary load.

Single or Two-Stage ?

Whether to select a single stage or a two stage flowsheet is a decision which occasionally arises. On the smaller plants where single filters will suffice and where the strength of the raw sewage is average, there is little doubt that a single stage plant offers the simplest solution. Where multiple filters are required because of size, it is generally possible to provide two stages of treatment at little added cost. Fig. 5 shows a comparison between the total flow including recirculation to be put through the clarifiers (primary and final) when using single-stage treatment and when using two-stage treatment. To achieve the same quality of effluent, the two-stage requires less tank capacity and conversely the same tank capacity will yield a better effluent with two-stage treatment than with single-stage. In each case tank requirements vary with recirculation, the determining factor.

In either single or two-stage plants it has proven most essential to remove continuously the humus sludge from the final tank due to its tendency to become septic rather quickly and deplete the oxygen in the effluent. As continuous removal usually results in a very thin sludge, current practice is to pump the humus sludge to the primary tank for consolidation with the raw sludge before the mixture is pumped to the digester. More recent practice utilizes this humus sludge outlet in the final clarifier as a source of recirculated material. Since it is withdrawn from the clarifier bottom it does not affect the amount overflowing at the tank surface and hence can be disregarded in determining the size of the final clarifier.

Conclusions

While these conclusions appear to be derived from data from a relatively small number of plants, it should be emphasized that if the data were available they would undoubtedly apply equally to a much greater number of single and two-stage plants.

Performance of the plants cited appears to be dependent primarily upon one factor, the ratio of recirculation. Dosing rate, loading of the filter or depth of filter have no significant effect within the range of values covered by the data.

For treatment of average municipal sewage in the smaller plants where one filter is feasible, single-stage filters appear to be most applicable and at the same time capable of producing effluents containing from 20 to 25 ppm BOD. For larger plants where multiple filters are necessary or where stronger than average sewage is to be treated, a two-stage series parallel arrangement of filters should yield a better effluent than single-stage for the same volume of tanks and filters and for the same volume of recirculation.

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(2) Report of the Sub-committee on Military Sewage of the Sanitary Engineering Committee of the National Research Council, May, 1946, published in "Sewage Works Journal" - September, 1946.

(3) A Basic Law for the Performance of Biological Filters by C. J. Velz, "Sewage Works Journal" - 1948, page 607.

(4) Efficiency Study of a Recirculating Sewage Filter at Centralia, Mo. by W. A. Moore, R. S. Smithland, C. C. Ruchhoft, "Sewage and Industrial Wastes", 1950, page 184.

(5) Recirculation Tests on High Rate Filter by Clyde C. Kennedy and Walter C. Roberts, "Sewage Works Engineering" - December, 1947, page 622.

TABLE 1. Single Stage Plants - Flow Rates and Filter Data

Ref. No.	Location	Sewage Flow MGD	Recirculation Ratio R	Clarifier Overflow Rate Gal per Day per sq ft Prim.	Clarifier Overflow Rate Gal per Day per sq ft Final	FILTER Area Acres	FILTER Depth Ft	FILTER Volume AcFt	FILTER Dosing Rate MGAD
1	Fremont, Ohio	1.75	1.5	1140	870	0.231	3.3	0.762	19.0
2	Great Neck, N.Y.	0.52	1.15	540	157	0.146	4.0	0.584	7.68
3	Oklahoma City, So.Side Plant First Stage	16.173	1.0	620	630	1.99	6.0	11.94	16.3
4	Richland, Wash. Plant II	2.169	2.76	500	500	0.238	4.5	1.070	19.6
5	Dothan, Ala.	0.548	2.31	650	280	0.199	3.0	0.597	15.0
6	Centralia, Mo. (4th Test Period)	0.098	0.95	197	140	0.0222	3.0	0.0666	8.65
7	Storm Lake, Ia., First Stage	1.388	2.14	340	760	0.203	8.0	1.624	21.5
8	Alisal, Calif. (1st Test Period)	0.588	3.06	770	2110	0.115	3.2	0.370	20.8

TABLE 2. Performance of Single Stage Plant, Based on B.O.D. Removal

Ref. No.	Location	B.O.D. Raw Sewage ppm	Estimated Removal by Settling %	B.O.D. of Settled Raw Sewage ppm	B.O.D. of Settled Raw Sewage Lbper day	B.O.D. of Settled Raw Sewage Lbper AcFt	B.O.D. of Settled Effluent ppm	B.O.D. of Settled Effluent Lbper day	B.O.D. of Settled Effluent Lbper AcFt	B.O.D. Removed from Settled Raw ppm	B.O.D. Removed from Settled Raw Lbper AcFt	Efficiency Based on Settled Raw %	Efficiency Based on Raw Sewage %
1	Fremont, Ohio	134	30.5	93	1360	1780	21	306	401	72	1379	77.5	84.3
2	Great Neck, N.Y.	187	36	120	519	888	20.2	88	151	99.8	737	83.1	89.2
3	Oklahoma City, So.Side Plant First Stage	463	35	303	40680	3400	66	8970	750	237	2650	78.0	85.8
4	Richland, Wash. Plant II	173	36	111	2003	1900	19.5	353	330	91.5	1570	82.7	88.7
5	Dothan, Ala.	230	35	150	685	1150	19	87	145	131	1005	87.4	91.7
6	Centralia, Mo. (4th Test Per.)	210(1)	36	134	109	1640	14	11.5	173	120	1467	89.4	93.3
7	Storm Lake, Ia., First Stage	690(1)	45(2)	380	4390	2700	61	706	435	319	2265	84.0	91.1
8	Alisal, Calif. (1st Test Period)	293	40(2)	176	865	2320	23.5	115	311	152.5	2009	86.6	92.0

(1) Weighted average of domestic and industrial wastes
(2) Includes flocculation of raw sewage

TABLE 3. Actual versus Computed Efficiency of B.O.D. Removal from Settled Raw Sewage in Single Stage Plants

Plant Ref. No.	% Efficiency of B.O.D. Removal from Settled Raw				Ratio % Actual / Computed		
	Actual	Computed on basis of 1951 Tent. Stds.	N.R.C. Formula	Velz Formula	1951 Tent. Stds.	N.R.C. Formula	Velz Formula
1	77.5	83.3	79.4	85.5	93.0	97.6	90.5
2	83.1	81.1	83.8	83.8	102.3	99.1	99.1
3	78.0	80.0	72.2	80.9	97.5	108.0	96.4
4	82.7	88.3	80.5	83.3	93.8	103.0	99.4
5	87.4	86.9	83.7	86.1	100.5	104.3	101.3
6	89.4	79.6	78.9	86.1	112.0	113.2	103.7
7	84.0	86.3	77.0	80.1	97.5	109.2	104.8
8	86.6	89.0	79.1	85.5	97.4	109.4	101.3
		Standard Deviation from Mean %			3.80	5.65	3.05

TABLE 4. Actual versus Computed Efficiency of Overall B.O.D. Removal in Single Stage Plants

Plant Ref. No.	% Efficiency of B.O.D. Removal from Raw Sewage				Ratio % Actual / Computed		
	Actual	Computed on basis of 1951 Tent. Stds.	N.R.C. Formula	Velz Formula	1951 Tent. Stds.	N.R.C. Formula	Velz Formula
1	84.3	88.4	85.7	89.9	95.4	97.4	92.8
2	89.2	87.9	89.6	89.6	101.5	99.7	99.7
3	85.8	86.9	81.9	87.5	98.8	104.8	98.2
4	88.7	92.7	87.5	89.3	96.0	101.3	99.4
5	91.7	91.4	89.3	90.9	100.5	102.7	101.0
6	93.3	87.0	86.5	91.1	107.0	107.8	102.4
7	91.1	92.5	87.3	89.1	98.5	104.3	102.3
8	92.0	94.4	87.5	91.3	97.5	105.0	100.7
		Standard Deviation from Mean %			2.53	3.03	2.10

TABLE 5. Two-Stage Plants - Filter in Series (Fig. 1c) - Flow Rates and Filter Data

Ref. No.	Location	MGD	Recirculation Ratio: First Stage R_1	Recirculation Ratio: Sec. Stage R_2	Clarifier Overflow Rate Gal. per Day per sq. ft.: Prim.	Clarifier Overflow Rate Gal. per Day per sq. ft.: Final	Primary Filter: Area Acres	Primary Filter: Depth Ft.	Primary Filter: Volume AcFt	Primary Filter: Dosing Rate MGAD	Secondary Filter: Area Acres	Secondary Filter: Depth Ft.	Secondary Filter: Volume AcFt	Secondary Filter: Dosing Rate MGAD
1	Winchester, Va.	1.932	1.52	2.63	1160	920	0.282	3.0	0.845	17.3	0.282	3.0	0.845	24.8
2	Bentonville, Ark.	0.343	1.67	2.78	550	810	0.079	5.0	0.394	11.6	0.054	5.0	0.268	24.1
3	Siloam Springs, Ark.	0.255	1.41	1.54	390	410	0.076	5.0	0.380	8.1	0.054	5.0	0.270	11.8
4	Liberty, N.Y.	1.13	1.78	1.65	1400	1160	0.115	3.0	0.345	27.2	0.115	3.0	0.345	26.0
5	Medford, Oregon	4.63	1.17	1.17	1675	1675	0.180	3.0	0.540	57.0	0.180	3.0	0.540	57.0

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TABLE 6. Performance of Two-Stage Plants, Filters in Series (Fig. 1c) - Based on B.O.D. Removal

Ref. No.	Location	B.O.D. Raw Sewage ppm	Estimated Removal by Settling %	B.O.D. of Settled Raw Sewage: ppm to Prim.	B.O.D. of Settled Raw Sewage: Lbper Day	B.O.D. of Settled Raw Sewage: Lbper AcFt	B.O.D. of Final Effluent: ppm	B.O.D. of Final Effluent: Lbper Day	B.O.D. of Final Effluent: Lbper AcFt	B.O.D. removed from Settled Raw: ppm	B.O.D. removed from Settled Raw: Lbper Acft	Efficiency: Based on Settled Raw %	Efficiency: Based on Raw Sewage %
1.	Winchester, Va.	243	30.5	169	2720	1610	20.1	323	191	148.9	1419	88.1	91.7
2.	Bentonville, Ark.	335	35	231	657	996	27.5	79	119	203.5	877	88.1	91.8
3.	Siloam Springs, Ark.	621	36.5	394	840	1290	34	72	111	360	1179	91.4	94.5
4.	Liberty, N.Y.	400	28	288	2710	3920	31	292	423	257	3597	89.3	92.3
5.	Medford, Oregon	215	26.5	158	6100	5630	21.1	813	743	136.9	4887	86.7	90.2

TABLE 7. Efficiency of B.O.D. Removal from Settled Raw Sewage in Two-Stage Plants (Fig. 1c)

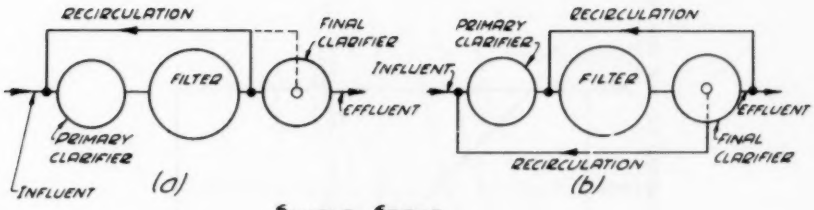
Plant Ref. No.	% Efficiency of B.O.D. Removal from Settled Raw			Ratio % Actual / Computed	
	Actual	Computed by 1951 Tent. Stds.	Computed by N.R.C. Formula	1951 Tent. Stds.	N.R.C. Formula
1	88.1	88.8	90.0	99.2	97.8
2	88.1	89.6	92.3	98.3	95.5
3	91.4	86.0	90.6	106.0	100.8
4	89.3	86.5	83.2	103.3	107.4
5	86.7	84.2	77.8	103.0	111.4
		Standard Deviation from Mean%		2.60	4.72

TABLE 8. Efficiency of Overall B.O.D. Removal in Two-Stage Plants (Fig. 1c)

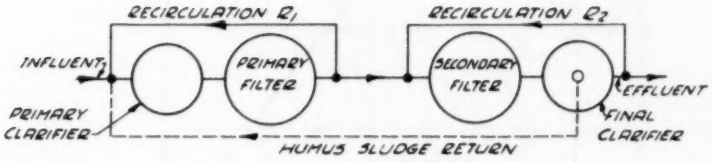
Plant Ref. No.	% Efficiency of B.O.D. Removal from Raw Sewage			Ratio % Actual / Computed	
	Actual	Computed by 1951 Tent. Stds.	Computed by N.R.C. Formula	1951 Tent. Stds.	N.R.C. Formula
1	91.7	92.2	93.0	99.5	98.6
2	91.8	92.8	95.0	98.9	96.5
3	94.5	91.2	94.0	103.5	100.5
4	92.3	90.3	87.9	102.2	105.2
5	90.2	88.4	83.7	102.0	107.8
		Standard Deviation from Mean %		1.60	3.24

TABLE 9. Performance of Two-Stage Plants Using Series-parallel Flowsheet (Fig. 1e)

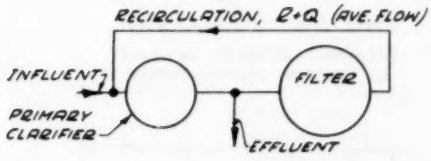
Plant Location	Orlando, Fla.	Petaluma, Calif.
Flow - MGD	3.90	0.505
Recirculation Ratio		
Primary R_1	1.6	1.43
Secondary R_2	2.06	2.43
Clarifier Overflow Rate		
Primary gal. per day per sq. ft.	600	880
Final " " " " " "	965	880
Filters		
Total Area Acre	1.04	0.203
Depth Ft.	5.0	3.0
Volume Acre Ft.	5.20	0.609
Dosing Rate MGAD		
Primary Filter	19.3	12.0
Secondary Filter	23.0	17.2
B.O.D. Raw Sewage ppm	176	576
Estimated Removal by Settling %	30	33
B.O.D. of Settled Raw Sewage		
ppm	123	385
Lb per Day	3960	1620
Lb per Ac Ft	760	2660
B.O.D. of Final Effluent		
ppm	10.6	14
Lb per Day	345	59
Lb per Ac Ft	66	97
B.O.D. Removed from Settled Raw		
ppm	112.4	371
Lb per Ac Ft	694	2563
Efficiency		
Based on Settled Raw	91.4	96.4
" " Raw Sewage	94.0	97.6
Computed Efficiency		
Based on Settled Raw	94.9	95.1
" " Raw Sewage	96.4	97.2



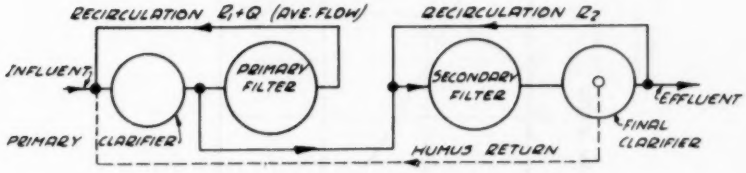
SINGLE STAGE



TWO STAGE – FILTERS IN SERIES (c)



SINGLE STAGE – INTERMEDIATE (d)



TWO STAGE – SERIES PARALLEL (e)

FIG. 1 TYPICAL BIOFILTRATION FLOWSHEETS

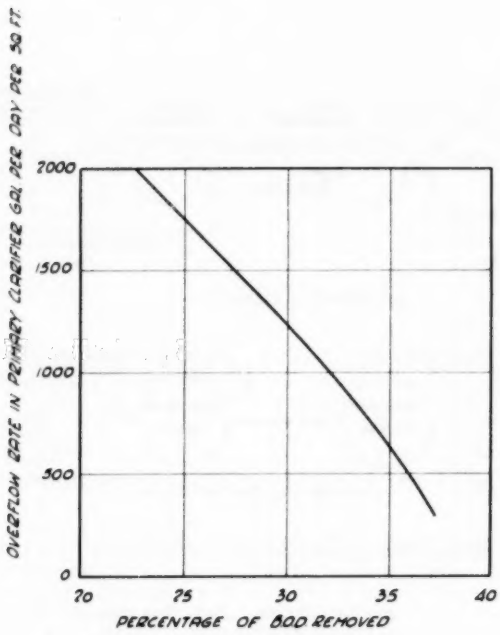


FIG. 2. ESTIMATED REMOVAL OF B.O.D BY PRIMARY SEDIMENTATION

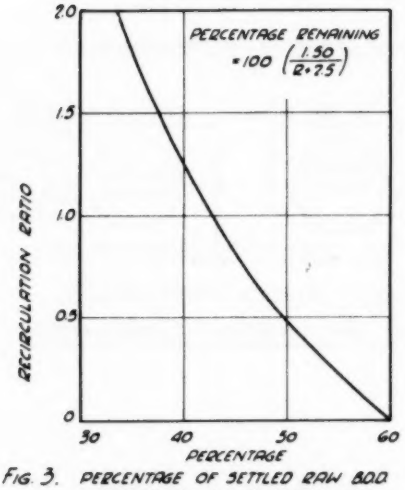


FIG. 3. PERCENTAGE OF SETTLED RAW B.O.D REMAINING IN EFFLUENT OF SINGLE STAGE INTERMEDIATE PLANT (FLOWSHEET 1-d)

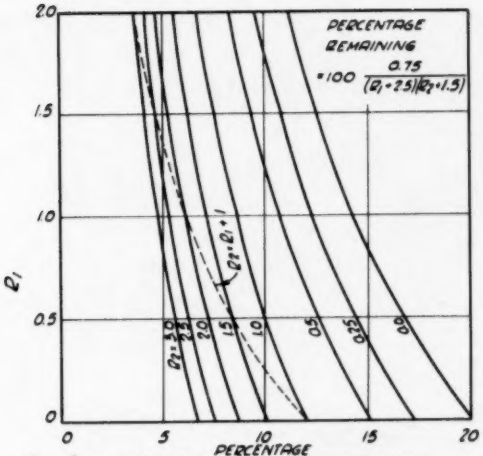


FIG. 4. PERCENTAGE OF SETTLED RAW B.O.D. REMAINING IN EFFLUENT OF TWO-STAGE SERIES PARALLEL PLANT (FLOWSHEET FIG. 1c)

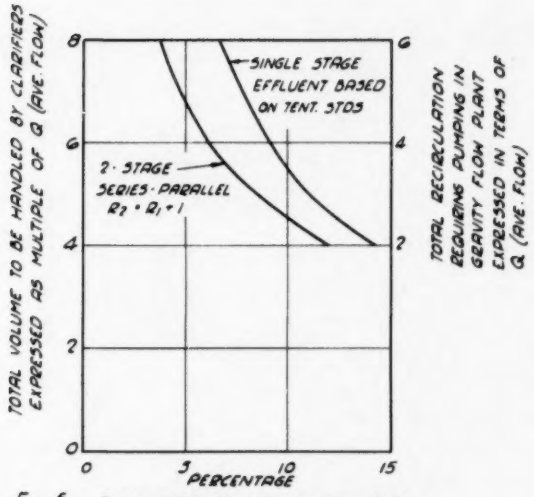


FIG. 5. PERCENTAGE OF SETTLED RAW B.O.D. REMAINING IN EFFLUENT